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PRELIMINARY INVESTIGATION OF EXTRUDING COMPOSITE TUNGSTEN — URANIUM DIOXIDE TUBING

by Charles P. Blankenship and Charles A. Gyorgak

Lewis Research Center
Cleveland, Ohio

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PRELIMINARY INVESTIGATION OF EXTRUDING COMPOSITE TUNGSTEN - URANIUM DIOXIDE TUBING*

by Charles P. Blankenship and Charles A. Gyorgak

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SUMMARY

An investigation was made of the feasibility of extruding composite tubing of tungsten - 20 volume percent uranium dioxide for fuel-element components. Both tungsten-clad and unclad composite tubing were successfully extruded over 1/2-inch-diameter mandrels at extrusion temperatures of 4000° and 3600° F. The tungsten composites, canned in molybdenum, were extruded at a reduction ratio of approximately 16 to 1.

After removal of the molybdenum, the extruded tubing was nominally 5/8 inch in diameter and the wall thicknesses were 0.050 and 0.030 inch for the clad and unclad tubing, respectively.

In all of the extrusions, excessive elongation of the dispersed uranium dioxide particles was noted in the recrystallized tungsten matrices. Subsequent testing is required to determine the suitability of the extruded tubing for fuel-element components.

INTRODUCTION

Nuclear propulsion systems (refs. 1 and 2) are of considerable interest for space vehicles. The proposed systems operate at extremely high temperatures, greater than 4000° F, and certain components must be fabricated from refractory metals. In the tungsten water-moderated nuclear rocket concept being studied at the Lewis Research Center, tungsten is considered a potential matrix material for dispersion-type fuel elements containing uranium dioxide (UO_2) as the nuclear fuel (refs. 1 to 3). Fuel elements of this type may have to be clad with unfueled tungsten to minimize fuel loss by volatilization at the high operating temperatures.

The design of such fuel elements depends primarily upon the heat-transfer require-

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ments of the reactor. A concentric-ring fuel element is of particular interest because of the large surface area available for heat transfer to the rapidly flowing hydrogen propellant. One proposed design consists of 10 concentric cylinders in a 2-inch-diameter configuration. Each cylinder has a wall thickness of 0.020 to 0.030 inch and a length of $1\frac{1}{2}$ inches. An average gap of 0.060 inch is provided between successive cylinders to allow passage of the hydrogen propellant through the fuel elements.

A method of forming the cylinders from flat plates is being developed (ref. 3). In this method, the cylinders are hot-formed from pressed, sintered, and clad sheet-bars of the tungsten-UO_2 composite that have been hot-rolled to the required thickness. Various methods for joining the formed cylinders are being investigated.

Since joining of fueled cylinders is a difficult problem and even successful joints represent potential weak points, a fabrication method to produce seamless cylinders is desirable. Accordingly, an investigation was conducted to determine if seamless, thin-wall, tungsten-UO_2 tubing could be extruded. Attempts were made to extrude 5/8-inch-diameter, 30-mil-wall tubing over a floating mandrel. This size is the smallest required in the proposed concentric-ring fuel element (ref. 3).

Initial extrusion parameters were investigated using composites of tungsten - 20 volume percent zirconia (ZrO_2). Zirconia was selected as a substitute dispersion since it was a readily available material, and its deformation characteristics were assumed to be somewhat similar to those of UO_2. The extrusion of tungsten-UO_2 composites both with and without tungsten cladding was subsequently investigated. These composites contained 20 volume percent UO_2, which is in the middle of the range of desired reactor fuel loadings of 10 to 30 volume percent (refs. 2 and 3). Extrudability of the composites was considered the most important aspect of this investigation.

MATERIALS, APPARATUS, AND PROCEDURE

Billet Preparation

Composites of tungsten - 20 volume percent ZrO_2 and tungsten - 20 volume percent UO_2 were prepared by conventional powder-metallurgy methods of dry blending, cold hydrostatic compaction, and sintering. The average particle size of the irregularly shaped ZrO_2 and the spherical UO_2 was approximately 30 to 60 microns, and the average particle size of the tungsten was 0.88 micron. The composites were hydrostatically pressed at 50,000 pounds per square inch into $3\frac{1}{2}$-inch-long hollow cylinders. After pressing, the cylinders were sintered in a hydrogen atmosphere at 3200° F for 4 hours. The as-sintered densities of the composites were in the range of 85 to 90 percent of theoretical, as measured by mercury intrusion.

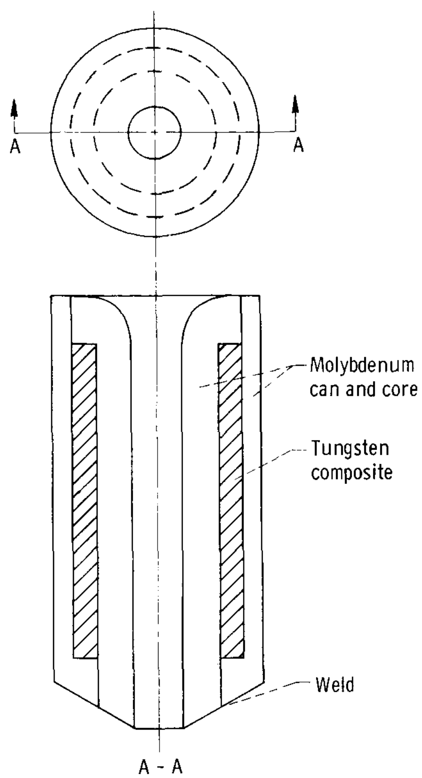

Figure 1. - Extrusion billet assembly.

The cylinders were ground to the required outside diameter of 1.740 inches and inside diameter of 1.320 inches and inserted into pressed, sintered, and machined molybdenum cans to complete the billet assembly shown in figure 1. Prior to assembly, a 1/2-inch-diameter hole was drilled through the molybdenum core for inserting the extrusion mandrel, and a 120° die mating angle was machined on the nose of the billet. The two components of the molybdenum cans were welded together, by the tungsten-inert gas (TIG) method as indicated in figure 1.

The composites were canned in molybdenum to reduce the effective reduction ratio required to extrude thin-wall tubing over a mandrel. In addition, the molybdenum should absorb any minor surface irregularities associated with the extrusion process and minimize contamination of the tubing. Composite size and billet configuration were determined by the dimensional requirements of the extruded tubing which were calculated to a reduction ratio of 18:1.

Six extrusion billets were prepared for investigating extrusion parameters. Two billets were made with tungsten-ZrO_2 composites, and the four remaining billets contained tungsten-UO_2 composites. Rolled tungsten sheets, 0.030 inch thick, were placed around the outer and inner diameters of two of the tungsten-UO_2 composites for co-extruding clad tubing.

Extrusion Tooling

The billets were extruded in a three-stage, 1000-ton vertical extrusion press equipped with 2-inch-diameter tooling. With this tooling, the maximum extrusion pressure was limited to 200,000 pounds per square inch. Alinement of the extrusion tooling was maintained within 0.003 inch of the centerline of the press. Zirconia-coated extrusion dies with an orifice of 0.695 inch and an entrance angle of 120° were used.

The floating mandrels employed in extruding the tubing were attached to the extrusion stem by means of an aluminum sleeve, as shown in figure 2. A graphite follower block and a steel dummy block were also enclosed in the sleeve attachment. The 1/2-inch-diameter, AISI H-12 steel mandrels were coated with zirconia, and were tapered 0.005 or 0.010 inch per inch over a 7-inch length. A typical ZrO_2-coated mandrel is

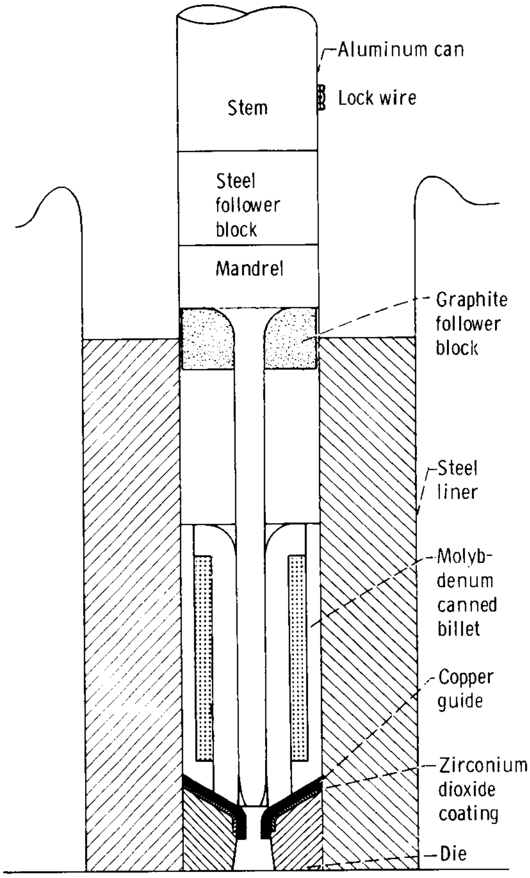

Figure 2. - Schematic of tooling arrangement for extruding tubing over mandrel.

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Figure 3. - H-12 tool steel extrusion mandrel coated with zirconium dioxide.

shown in figure 3. The 9-inch-long mandrels were designed so that they extended through the die orifice before the extrusion pressure was applied to the billet. In order to aline the mandrel with respect to the die orifice, a copper guide was placed in the die. The inside diameter of the guide was slightly smaller (approx. 0.010 in.) than the average mandrel diameter. This tooling arrangement is also shown in figure 2. A catcher device was attached to the die backer through the split-bolster assembly of the extrusion press. The purpose of this catcher device was to keep the tubing straight during extrusion. It consisted of a steel pipe assembly that was lined with bonded asbestos (Transite). The inside diameter of the asbestos lining was slightly larger (approx. 0.020 in.) than the diameter of the extruded tubing.

Experimental Procedure

The billets were inductively heated to the extrusion temperatures, 3600° to 4300° F,

[redacted]

under a flowing hydrogen atmosphere. Billet heating time was approximately 30 minutes. Temperature measurements were made by sighting on a blackbody hole in the billets with an optical pyrometer calibrated to the furnace. The billets were supported in the furnace on a stool attached to an air-operated cylinder. When the extrusion temperature was reached, the billets were dropped into a transfer device for rapid transport to the extrusion press container. The time required to transport the billet and to complete the extrusion cycle was 5 to 10 seconds.

Lubrication of the mandrels and dies was effected by a coating of tungsten disulfide. Various combinations of lubricants, including glass cloth, graphite cloth, and tungsten disulphide, were used in the extrusion liner.

An x, y, y-recorder with a full-scale travel in 0. 5 second was used to record simultaneously the extrusion pressure, the ram speed, and the ram displacement. A pressure transducer located in the high-pressure-valve block of the press measured the extrusion pressure. A 10-turn potentiometer and a linear potentiometer attached to the ram assembly measured displacement and speed, respectively.

Initial extrusion parameters, including temperature, extrusion pressure, and speed, were determined by extruding two tungsten-ZrO_2 composites, one at 4300° F and one at 4000° F. Extrusion temperatures for the tungsten-UO_2 composites were either 4000° or 3600° F. Attempts were made to control the extrusion speed by varying the throttle-valve opening of the press.

After the extrusions were completed, the tubing was removed from the catcher, visually inspected, sand-blasted, measured, and photographed. A 50 percent nitric acid aqueous solution was used to remove the molybdenum from the extruded tubing. The leached tubing was measured to determine wall thickness, tubing diameter, and concentricity. The density of the extruded tubing was determined by mercury intrusion techniques. Metallographic specimens were taken from the tail sections of the extruded tubing.

RESULTS AND DISCUSSION

Extrusion Data

The data obtained from extruding the composite tubing are summarized in table I. For each extrusion, except as noted, the extrusion pressure and ram speed were recorded as a function of ram displacement. The maximum recorded extrusion pressure for each extrusion is given in percent of press capacity for comparative purposes. Extrusion speeds are average values based on the average ram speed as recorded during extrusion.

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TABLE I. - TUNGSTEN-COMPOSITE TUBING EXTRUSTION DATA

[Reduction ratio, 16 to 1.]

Extrusion	Composite	Extrusion temperature, °F	Throttle valve opening, in.	Percent of press capacity required (a)	Extrusion speed, in./sec (b)	Extrusion time, sec (c)	Extruded length, in.	Mandrel taper, in./in.	Container lubricants
1	Tungsten -	4300	5/8	66	144	10	40	0.010	Glass cloth
2	zirconium	4000	1/4	72	72	7	46	.010	and tungsten
	dioxide								disulfide
3	Tungsten -	4000	1/2	63	108	7	32	.010	Glass cloth,
4	uranium	3600	1/2	85	(d)	7.5	51.5	.005	graphite cloth,
5	dioxide	4000	1/4	61	22	6	52	.005	and tungsten
6		3600	1/2	72	54	5.5	50	.005	disulfide

[a]Maximum press capacity with 2-in. tooling, 200,000 lb/sq in.

[b]Average ram speed times calculated reduction ratio, in./sec.

[c]Includes transfer time and time required for extrusion.

[d]Not measured because of instrumentation failure.

Tungsten - Zirconia Extrusions

Billets 1 and 2, containing the tungsten-ZrO_2 composites, were extruded at 4300° and 4000° F, respectively. Billet 1, extruded at 4300° F, required 66 percent of the press capacity (200,000 lb/sq in.) for 2-inch-diameter tooling. The average extrusion speed was 144 inches per second (ram speed times reduction ratio). Although the tubing remained intact, considerable surface tearing occurred during extrusion. Chemical removal of the molybdenum can revealed that these defects extended to, and in some cases through, the wall of the tungsten-ZrO_2 tubing. A section of the tubing after removal of the molybdenum is shown in figure 4. It is believed that the combination of extrusion temperature and speed was excessively high for the molybdenum-canned composite. The size of the extruded tubing, however, approached the calculated dimensions.

The extrusion temperature for billet 2 was lowered to 4000° F. Extrusion pressure increased to 72 percent of press capacity, while the extrusion speed decreased 50 percent to 72 inches per second. Considerable improvement was noted in the surface conditions of this extrusion. Lubricant was detected on the full length of the extrusion, and the surface finish was considered excellent. A section of the leached tubing from the tail of the extrusion is shown in figure 5. Except for a few ripples, the tubing was uniform and close to the desired dimensions.

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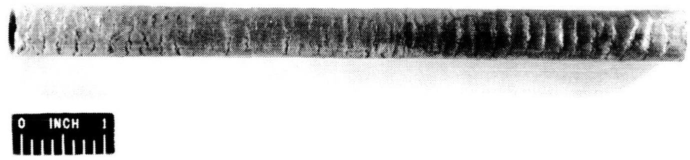

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Figure 4. - Section of leached tungsten - zirconium dioxide tubing extruded at 4300° F (extrusion 1).

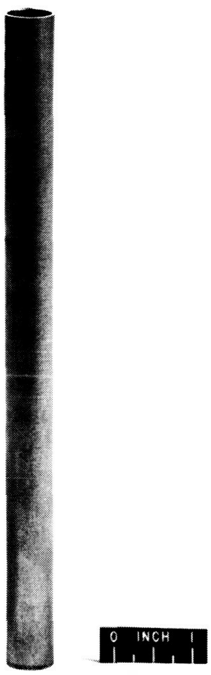

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Figure 5. - Section of leached tungsten - zirconium dioxide tubing extruded at 4000° F (extrusion 2).

Although optimum extrusion parameters were not determined for the tungsten-ZrO_2 composites, the feasibility of extruding refractory composite tubing was demonstrated, and data obtained from these two extrusions were used as guides for extruding tungsten-UO_2 composite tubing.

Tungsten - Uranium Dioxide Extrusions

The first tungsten-UO_2 composite, billet 3, was extruded at 4000° F. Extrusion pressure was 63 percent of press capacity, and the extrusion speed was 108 inches per second. The surface finish of the as-extruded tubing was considered excellent, which indicated that lubrication was adequate. Figure 6 shows a section of the tungsten-UO_2 tubing after the molybdenum had been removed. This section of tubing was taken near the tail of the extrusion, and as shown, the surface had a slight rippled appearance that may have been due to excessive extrusion speed and temperature. The tubing configuration, however, was essentially uniform throughout the entire length.

The extrusion temperature for billet 4 was lowered to 3600° F. Under these conditions, the extrusion pressure increased to 85 percent of press capacity. Extrusion speed was not determined because of instrumentation failure. As shown in figure 7(a), there were some surface tears in the molybdenum on the as-extruded tubing. Apparently, these defects were the result of lubrication failure; however, they did not extend to the tungsten composite, as shown in figure 7(b). Tubing uniformity and surface finish were improved in this extrusion over those obtained in billet 3.

Tungsten-Clad-Tungsten - Uranium Dioxide Tubing

The tungsten-UO_2 composite cylinders in billets 5 and 6 were wrapped with tungsten

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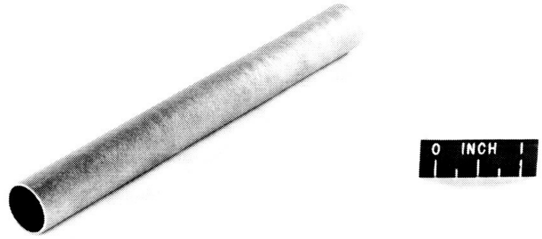

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Figure 6. - Section of leached tungsten - uranium dioxide tubing extruded at 4000° F (extrusion 3).

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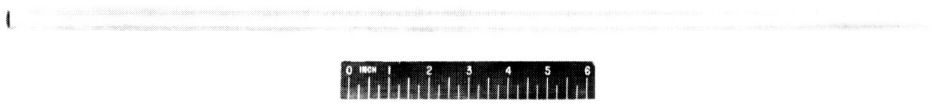
(a) As - extruded tubing.



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(b) Leached tubing.

Figure 7. - As-extruded and leached tungsten - uranium dioxide tubing extruded at 3600° F (extrusion 4).

sheet for coextrusion of clad tubing. Sixty-one percent of press capacity was required to extrude billet 5 at 4000° F, and the extrusion speed was 22 inches per second. For billet 6, extruded at 3600° F, 72 percent of press capacity was required. In this case, the extrusion speed was 54 inches per second. The as-extruded tubing from billets 5 and 6 with the mandrels and extrusion dies in their respective positions are shown in figures 8(a) and 9(a). Extrusion 5 had the better surface finish, however, only minor defects were present on the surface of extrusion 6. The erosion shown on the nose end of extrusion 6 resulted from a reaction between the molybdenum and the copper guides in the extrusion dies. This reaction is more pronounced on extrusion 6, but it occurred on all six of the extrusions. Only 8 to 12 inches of the molybdenum cans were affected by this erosion.

Figures 8(b) and 9(b) show the tungsten-clad composite tubing after removal of the molybdenum. Both extrusions exhibited striations in the tungsten cladding on the inner and outer surfaces, and the striations extended the entire length of the tubing. Most likely, the striated surfaces were due to the dissimilar deformation characteristics of the wrought tungsten and the sintered molybdenum. At the relatively high extrusion temperatures, the large grain size of the wrought tungsten may also have contributed to the

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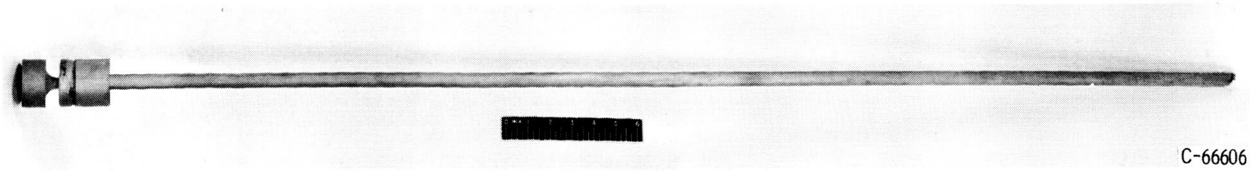
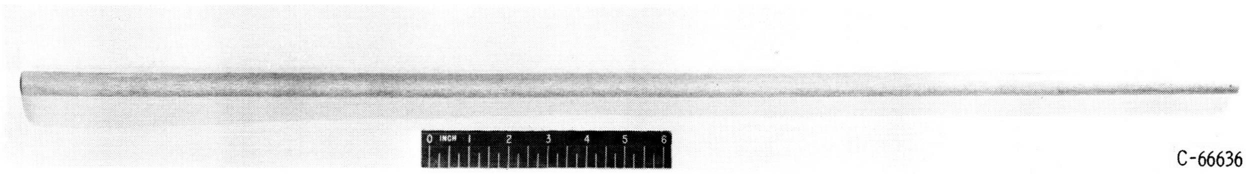
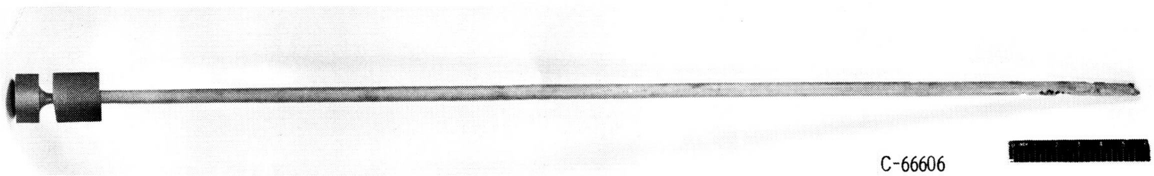


(a) As-extruded tubing.

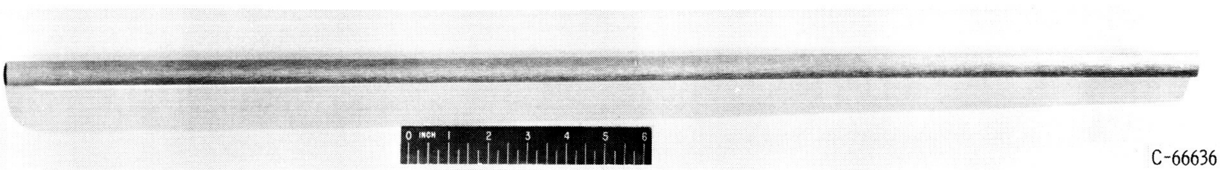


(b) Leached tubing.

Figure 8. - As-extruded and leached tungsten-clad-tungsten - uranium dioxide tubing extruded at 4000° F (extrusion 5).



(a) As-extruded tubing.



(b) Leached tubing.

Figure 9. - As-extruded and leached tungsten-clad-tungsten - uranium dioxide tubing extruded at 3600° F (extrusion 6).

formation of the striated surfaces noted in this coextrusion process. This type of striated surface has been observed previously by the authors in the extrusion of cast tungsten that was canned in sintered molybdenum. In order to eliminate the tungsten-clad striations, a compatibility study of sintered and/or wrought can-clad materials is required to determine a combination that would yield a smooth interface during coextrusion.

Except for the striated surfaces, the clad tubing was sound and of uniform size. The tungsten cladding varied in thickness from 0.004 to 0.006 inch.

PROCESS EVALUATION

The dimensional data of the extruded and leached tubing are summarized in table II. Although the measured dimensions are average values, the maximum deviation was not greater than 0.010 inch. Concentricity measurements were not conclusive since most of

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TABLE II. - DIMENSIONAL DATA FOR EXTRUDED AND

LEACHED TUNGSTEN-COMPOSITE TUBING

Extrusion (a)	Outside diameter, in.		Wall thickness, in.		Length, in.
	Average	Deviation	Average	Deviation	
2	0.620	±0.005	0.036	±0.004	42
3	.630	±.005	.036	±.005	32
4	.630	±.005	.030	±.003	42
5	.650	±.010	.054	±.003	42
6	.655	±.005	.050	±.005	42

[a]Extrusion 1 was not measured.

the tubes were slightly bent. Bending occurred during removal from the catcher before the extrusions had sufficiently cooled. The degree of bending varied from 0.040 to 0.100 inch in 2 to 3 feet; however, the tubing diameter and wall thickness were close to the calculated values.

For comparative purposes, photomacrographs of the extruded and leached tubes of each composite are shown in figure 10. The slightly striated surface of the ZrO_2 and unclad UO_2 composites resulted from removal of the dispersed surface stringers by the nitric acid. As previously noted, the striated surface of the clad tubing resulted from the difference in deformation characteristics of the molybdenum and the tungsten.

Since the densities of the extrusion billets were only 85 to 90 percent of theoretical, the reduction ratios of the extrusions were recalculated on the basis of the size of the extruded tubing. On this basis, the reduction ratios were approximately 16 to 1. The extruded tubing was determined to be fully dense by mercury intrusion density measurements.

In order to examine uniformity of billet deformation, the extrusion butts from extrusions 3 and 5 were sectioned longitudinally. Photomacrographs of these sections are shown in figure 11. It is evident from these photographs that the deformation of the composite with respect to the molybdenum can was uniform. The cracks in these sections occurred when the extrusion butts were stripped from the liner after completion of the extrusion.

The effects of temperature and pressure on the extrusion mandrels were of particular interest in this investigation. Generally, the ZrO_2 coating heat checked, but it remained intact with the steel mandrel, as shown in figure 12. Removal of the mandrels from the extrustions was relatively easy except for two of the extrusions in which the mandrels were slightly bent. Bending occurred, most likely, during the stripping operation, and the ZrO_2 coating spalled from the bent mandrels. Although the mandrels were tapered 0.005 or 0.010 inch per inch, no significant difference was noted in tubing uni-

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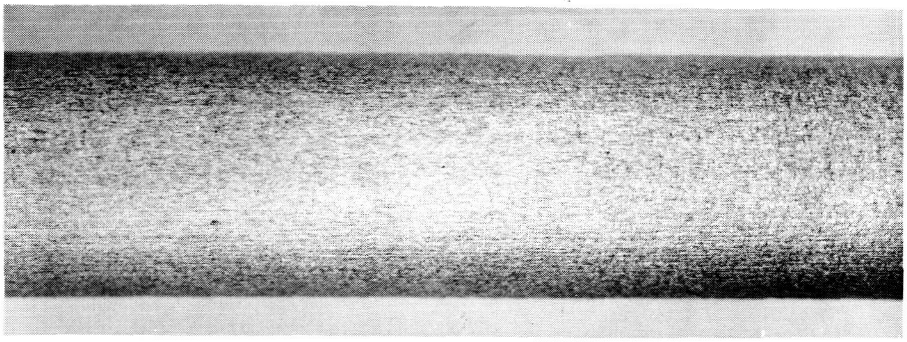
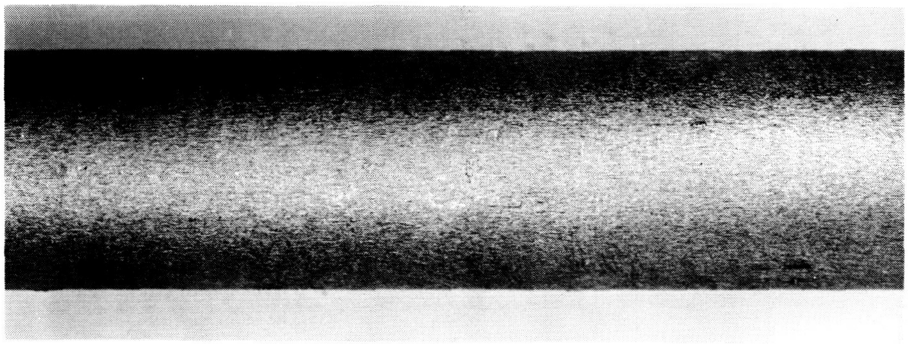
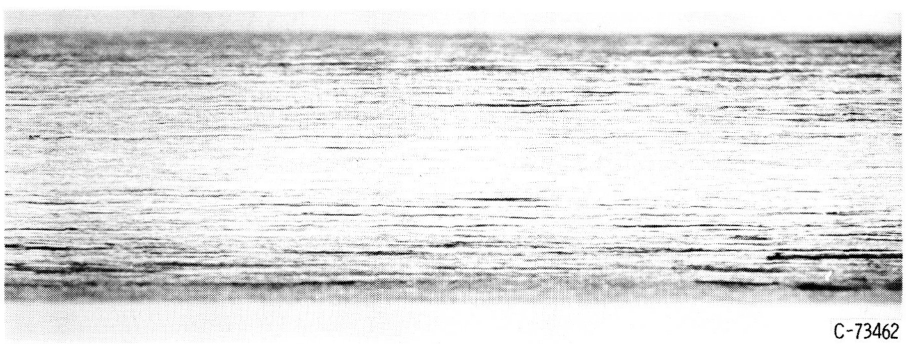


(a) Tungsten - zirconium dioxide extruded at 4000° F, extrusion 2.



(b) Tungsten - uranium dioxide extruded at 4000° F, extrusion 3.



(c) Tungsten-clad-tungsten - uranium dioxide extruded at 4000° F, extrusion 5.

Figure 10. - Extruded and leached tubing. X2.

formity or extrusion pressure for the different tapers.

In most of the extrusions, lubrication appeared to be adequate on the mandrels, the liner, and the dies. Between the two combinations of lubricants used in the extrusion liner, no appreciable difference in either extrusion surface quality or extrusion pressure was observed.

Metallographic Studies

Photomicrographs of the transverse and longitudinal sections of the extruded tubing

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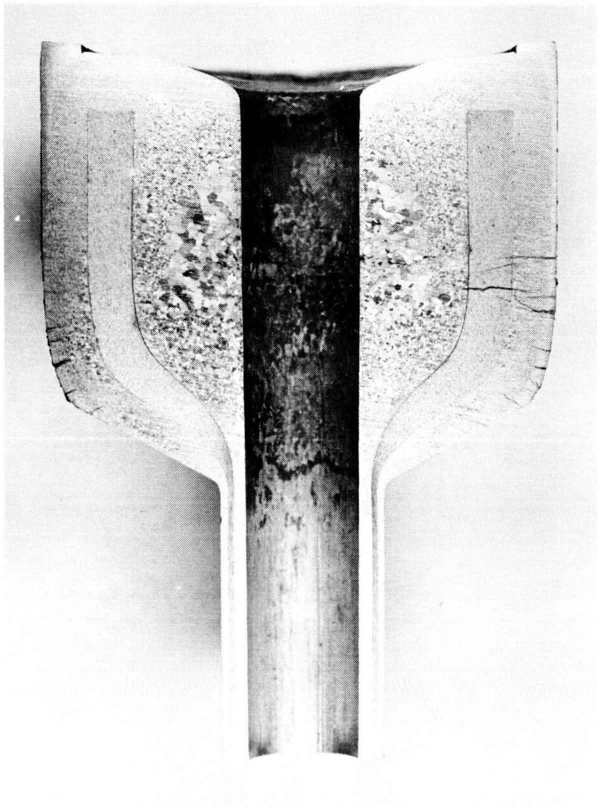
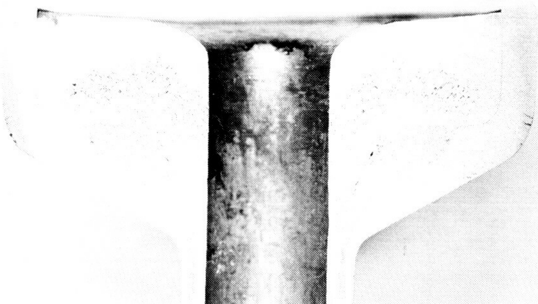


(a) Extrusion 3.



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(b) Extrusion 5.

Figure 11. - Extrusion butts. X2.

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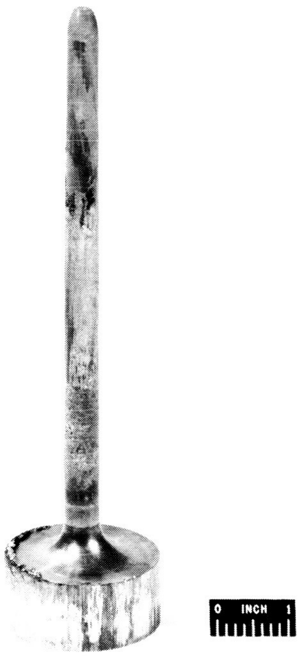

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Figure 12. - Typical used extrusion mandrel.

are shown in figures 13 to 18. In each composite extrusion, the tungsten matrix was recrystallized.

A longitudinal section of the tungsten-ZrO_2 composite extruded at 4300° F (extrusion 1) is shown in figure 13(a). The small amount of particle elongation indicates that the tungsten matrix was quite plastic under the extrusion conditions. As noted, however, the composite was fractured during the extrusion process. Figure 13(b) is a transverse section showing a typical fracture area. Distribution of the ZrO_2 dispersion was fairly uniform in the composite. The second tungsten-ZrO_2 composite (extrusion 2), extruded at 4000° F, exhibited a severely elongated structure, as shown in figure 14. Apparently, the matrix plasticity was decreased considerably as a result of the lower extrusion temperature.

Photomicrographs of transverse and longitudinal sections of the unclad-tungsten - UO_2 composites, extrusions 3 and 4, are shown in figures 15 and 16, respectively. Although the extrusion temperatures were 4000° and 3600° F, respectively, there was apparently no significant difference in the microstructures. In both of these extrusions, plastic deformation of the UO_2 particles was quite pronounced, as shown in the photomicrographs of longitudinal sections in figures 15 and 16. Particle elongation was approximately 16 to 1. Distribution of the oxide in the tungsten matrices appeared to be fairly uniform in these composites.

Photomicrographs of the tungsten-clad-tungsten - UO_2 composites, extrusions 5 and 6 are shown in figures 17 and 18, respectively. In these figures, the longitudinal sections show the elongated UO_2 structures typical of these extruded composites. Of all the tube sections examined, extrusion 5 exhibited the most nonuniform oxide distribution. This nonuniformity probably resulted from insufficient control of powder blending and compacting techniques used in preparing the original billet. Nonuniform oxide distribution, however, does not readily account for the duplex grain size of this composite shown in figure 17. Most likely, the abrupt change in grain size at the center of the composite resulted from complex temperature gradients encountered during extrusion. By comparison, the oxide distribution, as well as the grain size, in extrusion 6 was more uniform; however, the oxide concentration was apparently greater. The grain size of this composite was very close to the smaller grains of the duplexed structure in extrusion 5.

Comparison of the microstructures of the clad and unclad composites, figures 15

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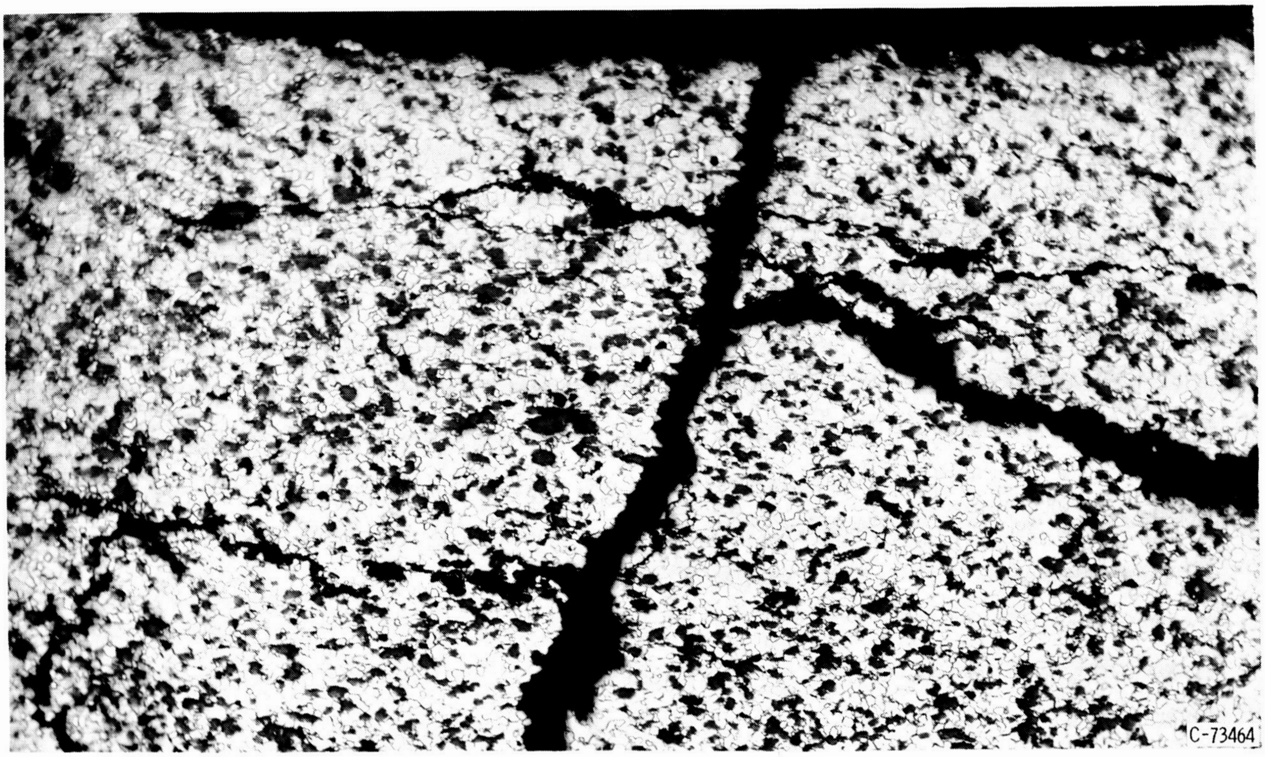
(a) Longitudinal section.



(b) Transverse section.

Figure 13. - Microstructure of tungsten - zirconium dioxide composite extruded at 4300° F (extrusion 1). Etchant, Murakami's reagent. X100.

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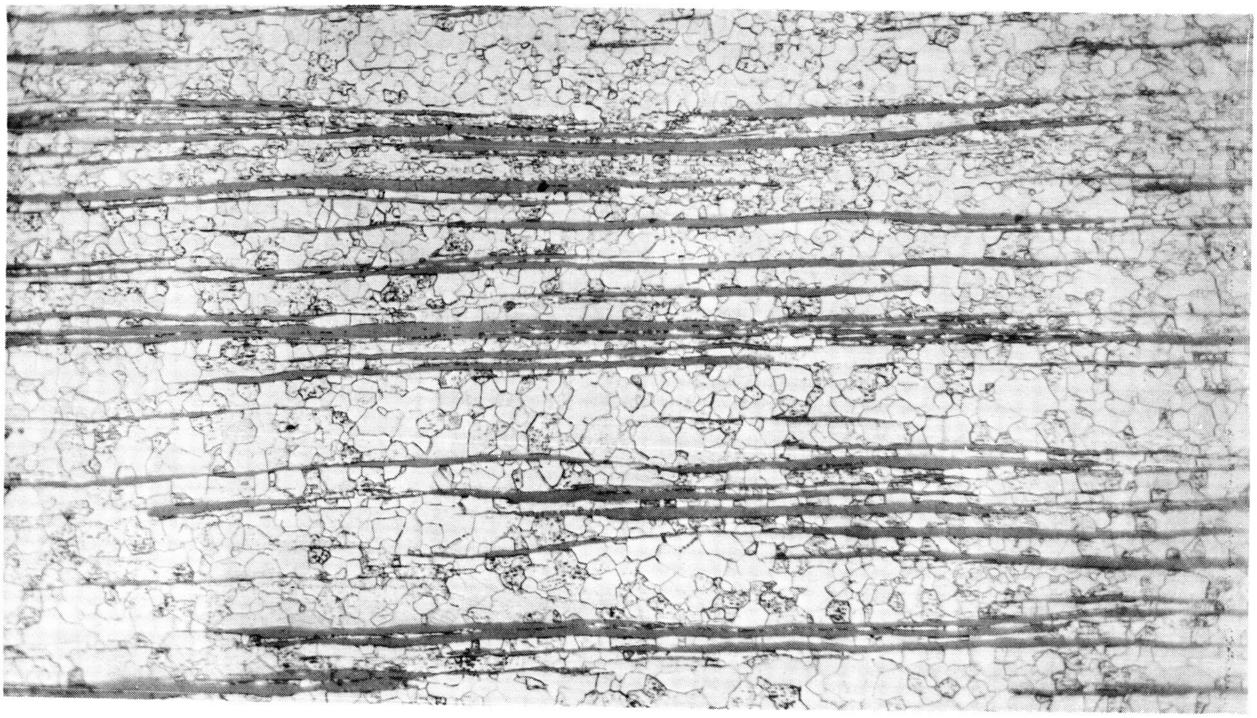
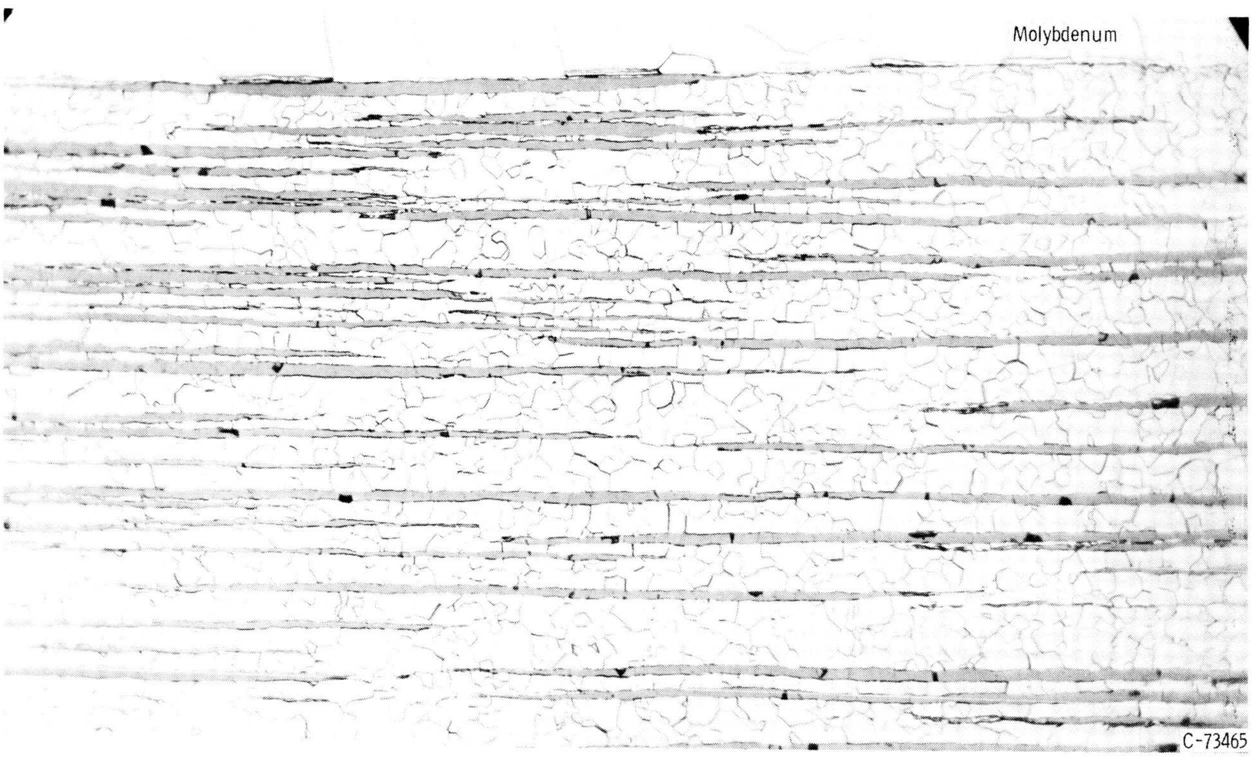


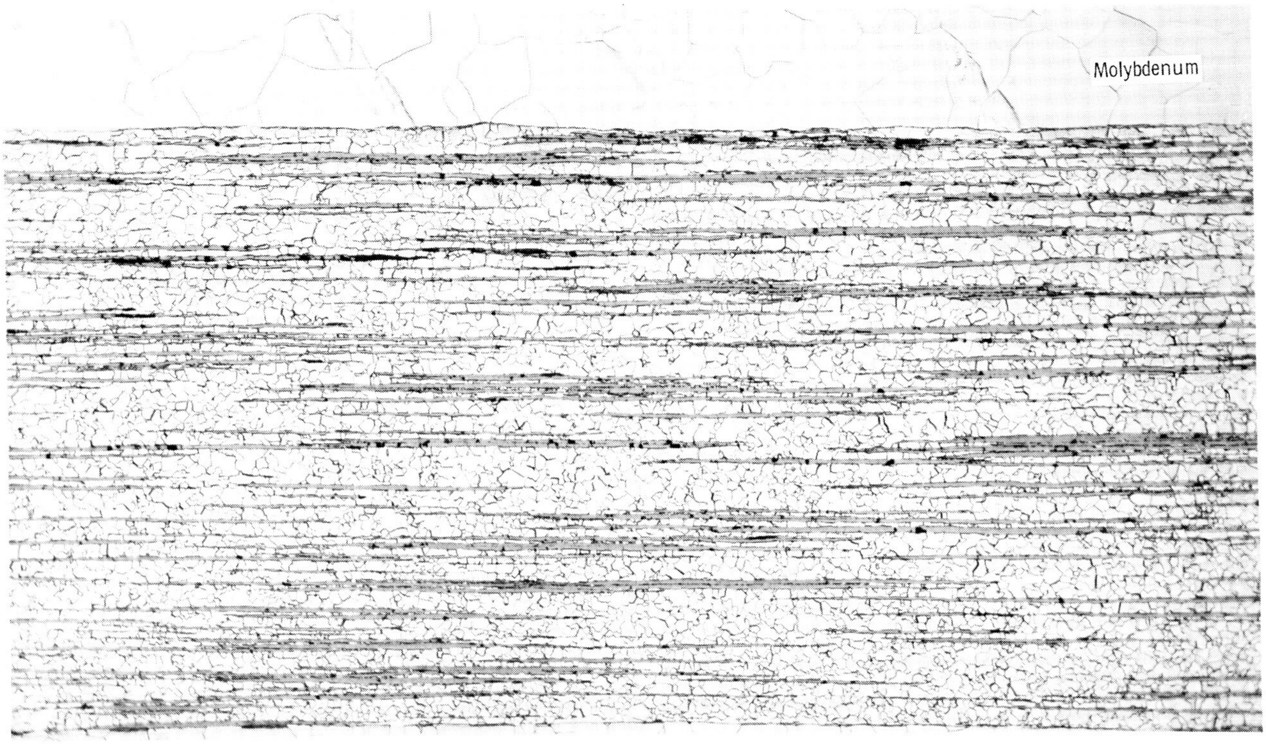
Figure 14. - Microstructure of tungsten - zirconium dioxide extruded at 4000° F (extrusion 2). Longitudinal section; etchant, Murakami's reagent. X250.



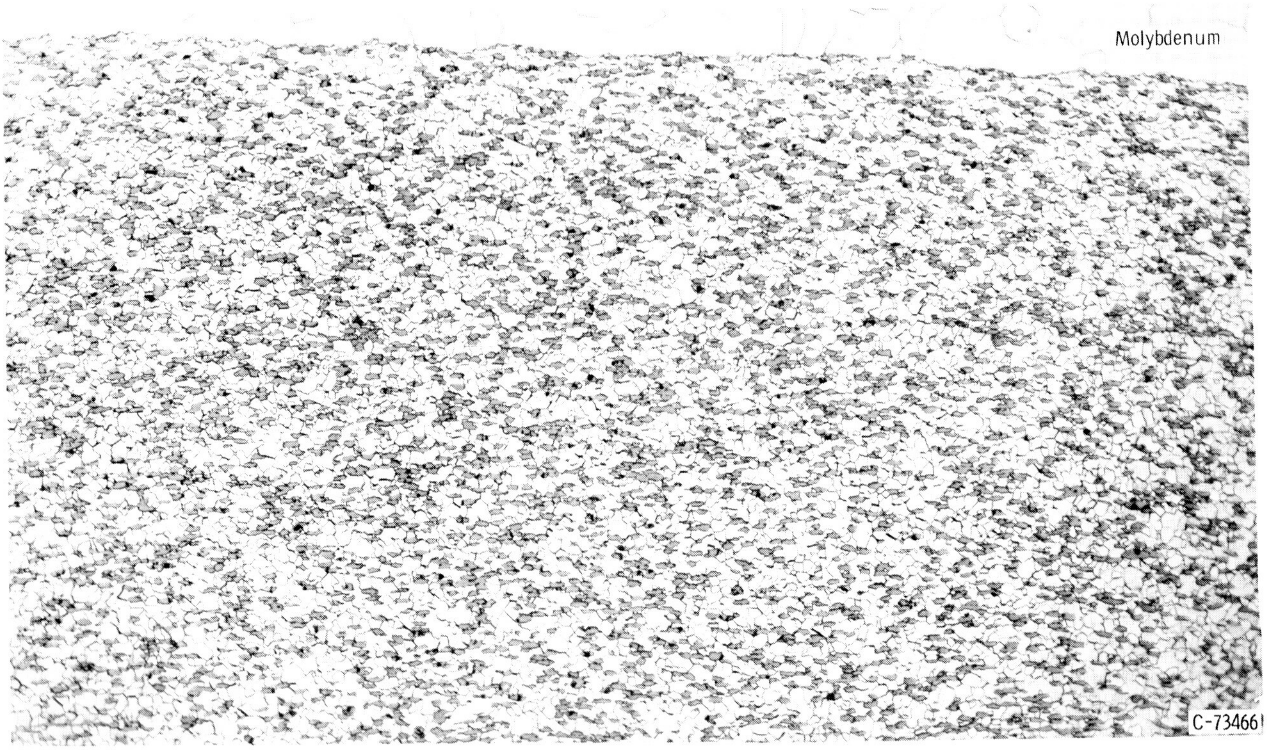
(a) Longitudinal section. X250.

Figure 15. - Microstructure of tungsten - uranium dioxide extruded at 4000° F (extrusion 3). Etchant, Murakami's reagent.

[redacted]



(b) Longitudinal section. X100.



(c) Transverse section. X100.

Figure 15. - Concluded. Microstructure of tungsten - uranium dioxide extruded at 4000° F (extrusion 3). Etchant, Murakami's reagent.

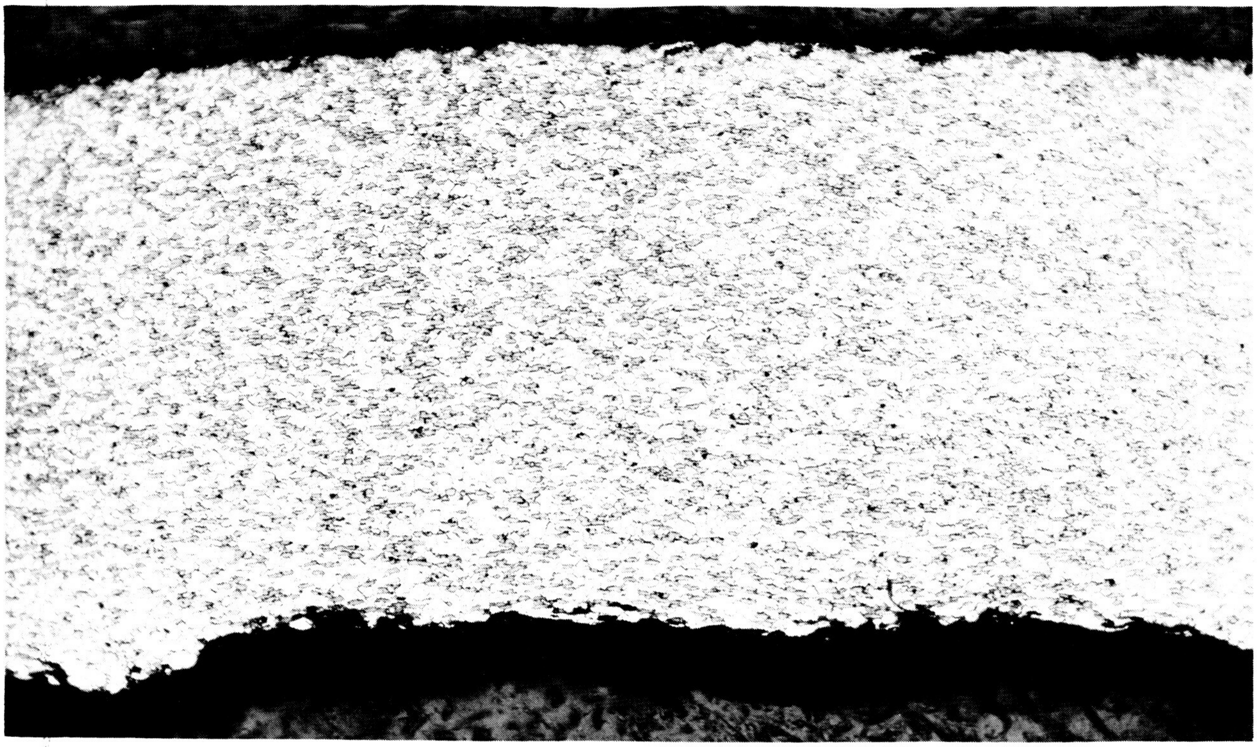
[redacted]

(a) Longitudinal section. X250.

(b) Longitudinal section. X100.

Figure 16. - Microstructure of tungsten - uranium dioxide extruded at 3600° F (extrusion 4). Etchant, Murakami's reagent.

[redacted]

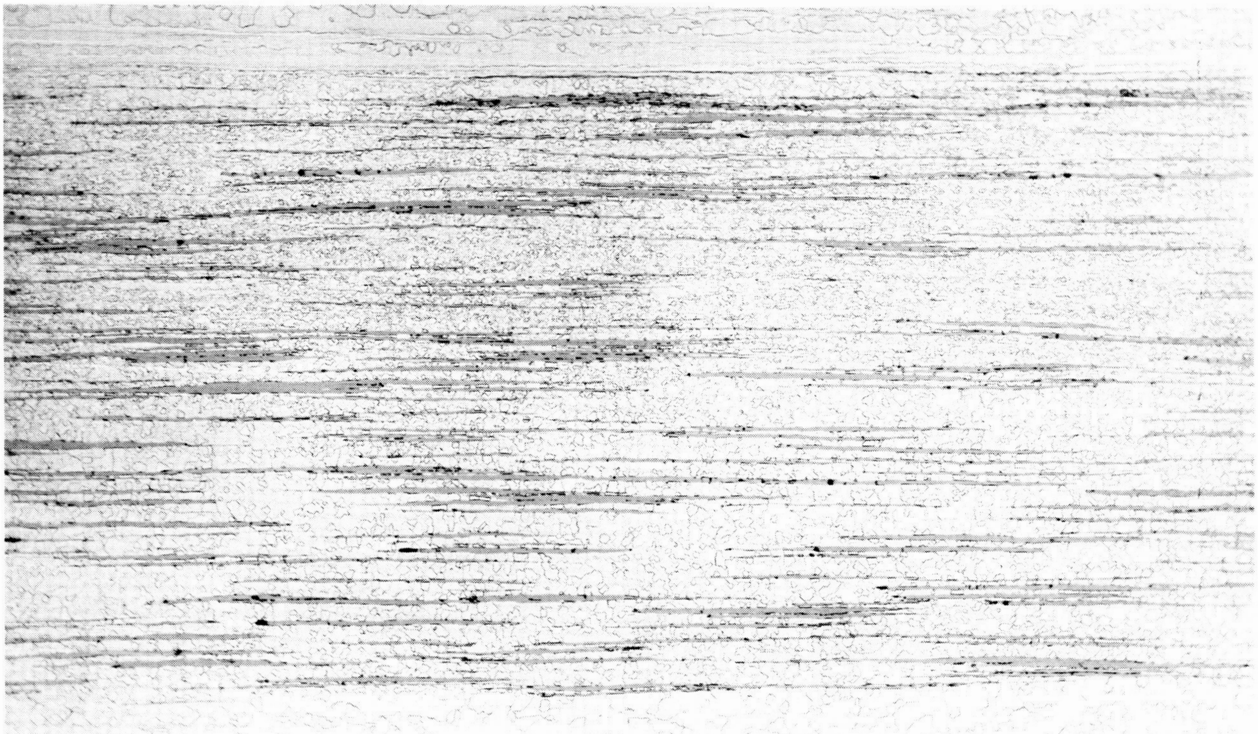


(c) Transverse section. X100.

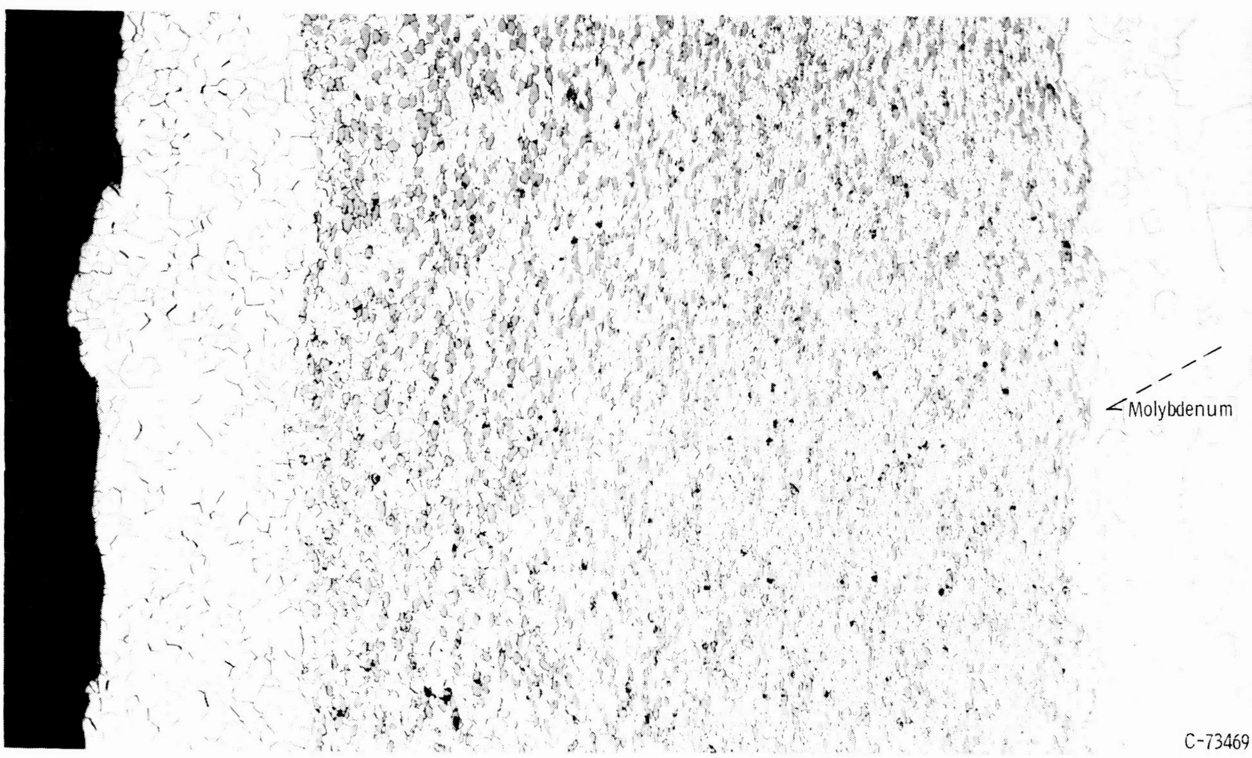
Figure 16. - Concluded. Microstructure of tungsten - uranium dioxide extruded at 3600° F (extrusion 4). Etchant, Murakami's reagent.

(a) Longitudinal section. X250.

Figure 17. - Microstructure of tungsten-clad-tungsten - uranium dioxide tubing extruded at 4000° F (extrusion 5). Etchant, Murakami's reagent.

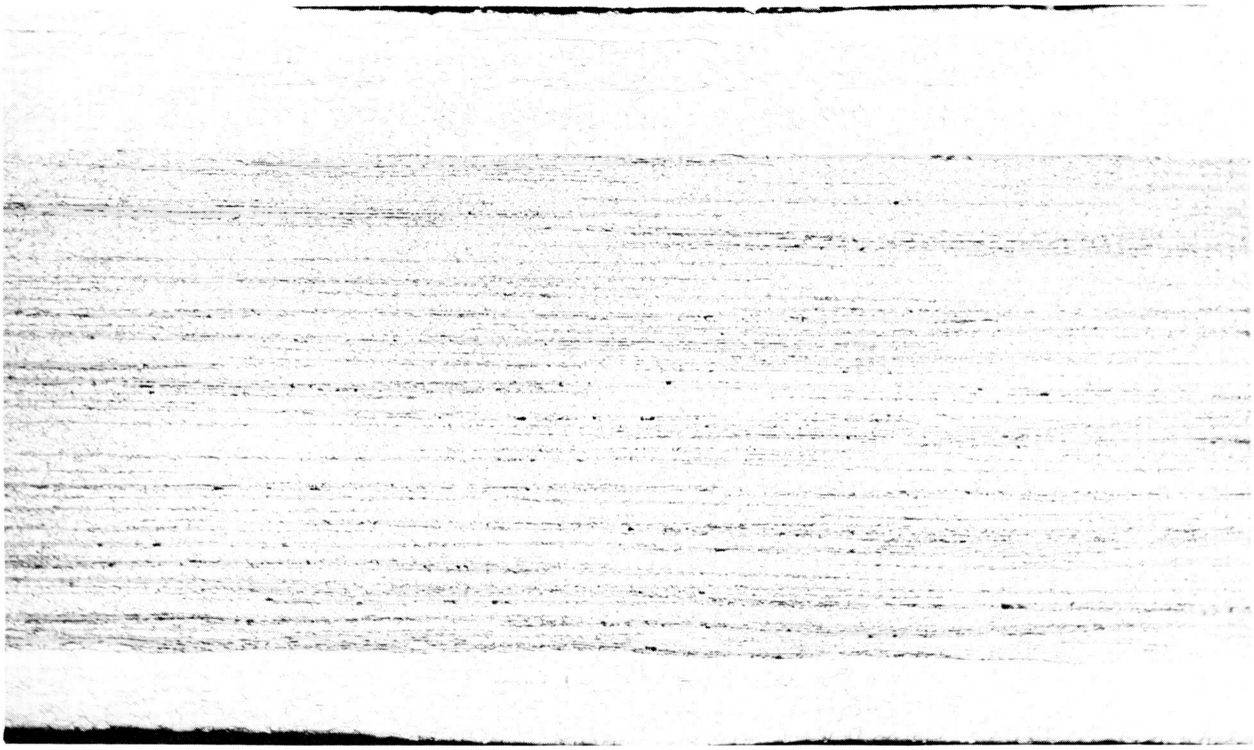


(b) Longitudinal section. X100.



(c) Transverse section. X100.

Figure 17. - Concluded. Microstructure of tungsten-clad-tungsten - uranium dioxide tubing extruded at 4000° F (extrusion 5). Etchant, Murakami's reagent.

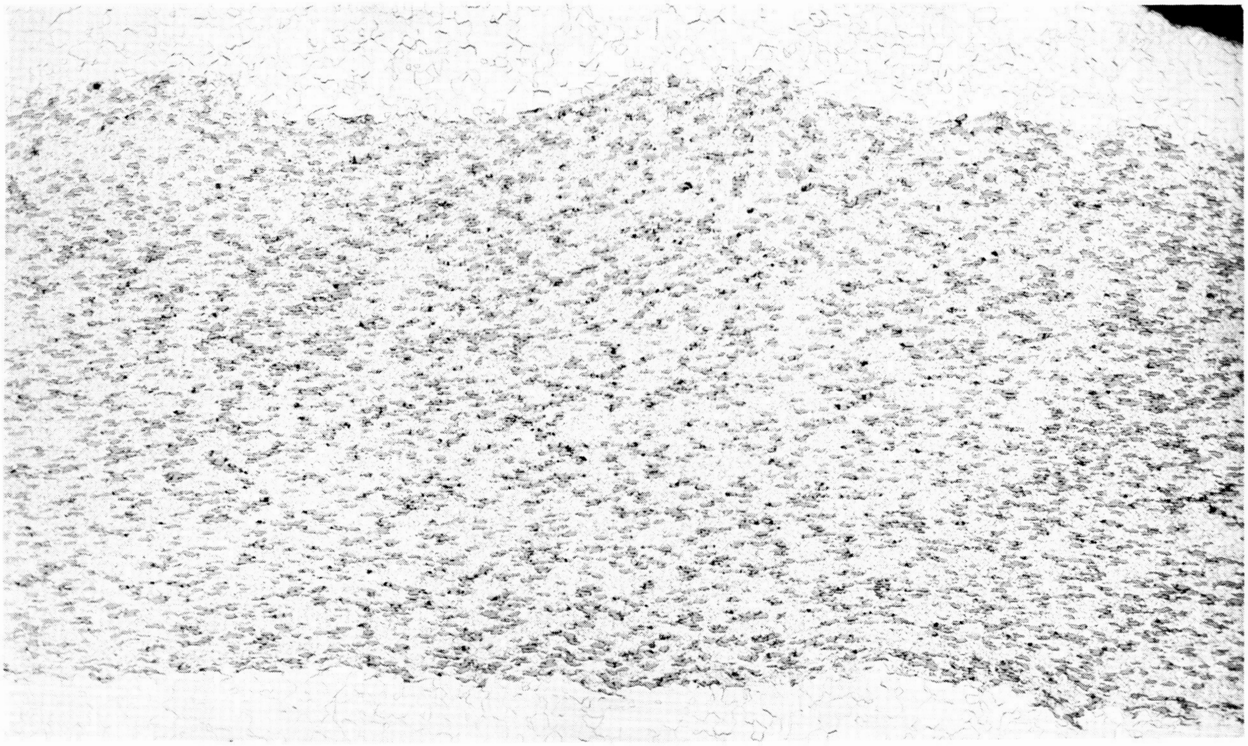


(a) Longitudinal section. X250.

(b) Longitudinal section. X100.

Figure 18. - Microstructure of tungsten-clad-tungsten - uranium dioxide tubing extruded at 3600° F (extrusion 6). Etchant, Murakami's reagent.

[redacted]



(c) Transverse section.

Figure 18. - Concluded. Microstructure of tungsten-clad-tungsten - uranium dioxide tubing extruded at 3600° F (extrusion 6). Etchant, Murakami's reagent.

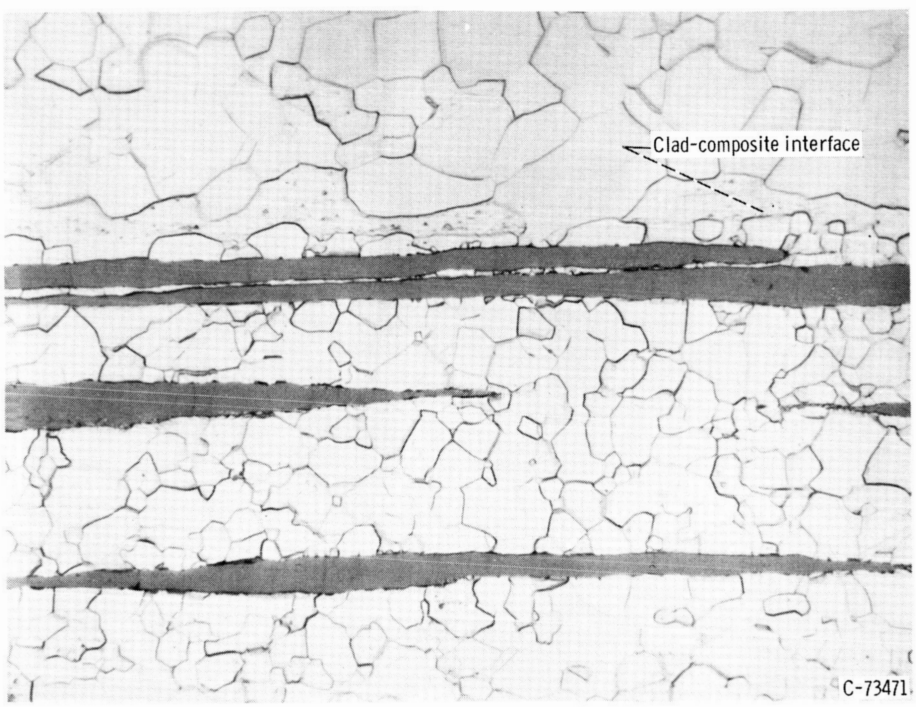


Figure 19. - Microstructure of tungsten-clad-tungsten - uranium dioxide tubing showing clad-composite interface (extrusion 3). Etchant, Murakami's reagent.

[redacted]

to 18, indicates that the grain size of the latter composite was larger. The larger grain size of the unclad composites probably resulted from the higher temperatures of the extrusions associated with the greater rates of deformation.

The described surface irregularities in the tungsten cladding can be observed in the transverse sections of the clad tubing (figs. 17(c) and 18(c)). From the photomicrograph of the clad-composite interface (fig. 19), it is apparent that a metallurgical bond was obtained between the cladding and the composite.

CONCLUDING REMARKS

The suitability of the extruded tungsten-UO_2 composites for fuel-element components will have to be determined by subsequent testing. Present metallographic analysis does indicate, however, that the structures obtained in the extruded tubing may not be ideal for use in concentric-ring fuel elements. First, and most important, the excessive elongation of the dispersed UO_2 is expected to be detrimental to the transverse properties of the tubing. Second, nonuniform dispersion of the UO_2 appears to accentuate particle-to-particle contact, especially if the dispersed particles are elongated. Fuel loss during operation might be excessive if dispersed particle-to-particle contact existed throughout the structure.

Steps can be taken to improve the structure of the extruded composites. By decreasing the effective reduction ratio, elongation of the UO_2 could be reduced a proportional amount. A more plastic tungsten matrix with respect to the UO_2 would also tend to decrease particle elongation. Additional studies are required to determine parameters, such as extrusion temperature, that may increase the plasticity of the matrix relative to that of the oxide dispersion. Obtaining a more uniform dispersion in the matrix would depend upon improved control of the blending and compacting techniques used in billet preparation.

SUMMARY OF RESULTS

A preliminary study was made to determine the feasibility of extruding tungsten - uranium dioxide tubing for fuel-element components. The results are as follows:

1. Tungsten clad and unclad composite tubing of tungsten - 20 volume percent uranium dioxide was extruded over 1/2-inch-diameter mandrels at a reduction ratio of approximately 16 to 1. Extrusion temperatures for the molybdenum-canned composites were 4000° and 3600° F. After removal of the molybdenum, the extruded tubing was nominally 5/8 inch in diameter and the wall thicknesses were 0.050 and 0.030 inch for

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the clad and unclad tubing, respectively.

2. The major surfaces of the composite tubing can be clad with unfueled tungsten by coextrusion techniques. The resultant cladding is metallurgically bonded to the composite.

3. In all of the extrusions, excessive elongation of the dispersed uranium dioxide was noted in the recrystallized tungsten matrices. Subsequent testing is required to determine the suitability of the extruded tubing for fuel-element components.

Lewis Research Center,
National Aeronautics and Space Administration
Cleveland, Ohio, December 11, 1964.

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